Low temperature Caesiums ion source in a standalone FIB system used for imaging and milling processes

T. Loeber, B. Laegel, G. von Freymann
Nano Structuring Center, Rheinland-Pfaelzische Technische
Universitaet Kaiserslautern-Landau
loeber@physik.uni-kl.de

Gallium focused ion beam (FIB) is a long-established standard tool in micro and nano structuring. Since last year we are using a new kind of FIB with a low temperature Caesium ion source, commercially available by the company ZeroK Nanotech, (Gaithersburg, MD, U.S.). The Cs ions are cooled down with lasers in several stages to almost 0 K. Due to the low energy spread of the ions (0.45 eV; compared to 5 eV for Ga) the Cs FIB can use low acceleration voltages between 2 to 16 kV with an ion beam current from 1 to 1000 pA. Because of the lower acceleration voltage, the Cs ions have a smaller penetration depth in the material compared to, e.g., Ga ions with a standard energy of 30 keV. Also, the Cs FIB has a much smaller spot size (~ 2 nm) at small currents, so it is possible to take images at a much higher resolution and to mill finer structures. The sputter yield of Cs ions at 16 kV is similar to that of Ga ions at 30 kV because of the higher Cs ion mass, so comparable milling times can be achieved.

In this work we show our first results with this new kind of Cs FIB. All of the results are compared with measurements achieved with a standard FEI Dualbeam Helios 650 NanoLab Ga FIB. For ion beam characterization purposes tests are done, e.g., high resolution images are taken of a graphite pen. Because of the smaller spot size of the Cs beam these images show much more details. Also, the depth of focus of the Cs FIB is measured. It is about 140 µm while the Ga FIB has a depth of focus of only about 40 µm. Cross section images of AlGaAs/GaAs semiconductor layers are taken with both systems. The Cs ion images show a much better material contrast compared to those obtained with Ga ions or electrons (see Fig. 1). Even a difference in the material composition *X* of the $Al_XGa_{1-X}As$ layer can be seen nicely.

Beside imaging the Cs FIB is also used for structuring of different materials. For example, rectangles milled in silicon with Cs ions have a different cross section than those milled with Ga. Two such cross sections can be seen in Fig. 2 where the bottom of the rectangle milled with Cs is much flatter and does not show any “trenches” at the side as is the case with Ga ion milling. The sidewall angle is almost the same (around 8°) for both rectangles. Silver is another material which is structured. Milled with Ga the polycrystalline Ag layer has a very inhomogeneous sputter rate. This can be seen in Fig. 3 a) where either the Ag layer is completely removed and the underlaying Si is milled into or clusters of Ag are still remaining. Milled with Cs the Ag layer is almost completely removed while the substrate is undamaged (see Fig. 3 b)).

In conclusion the Cs FIB has the potential to continue the work beyond the limitations of a Ga FIB .

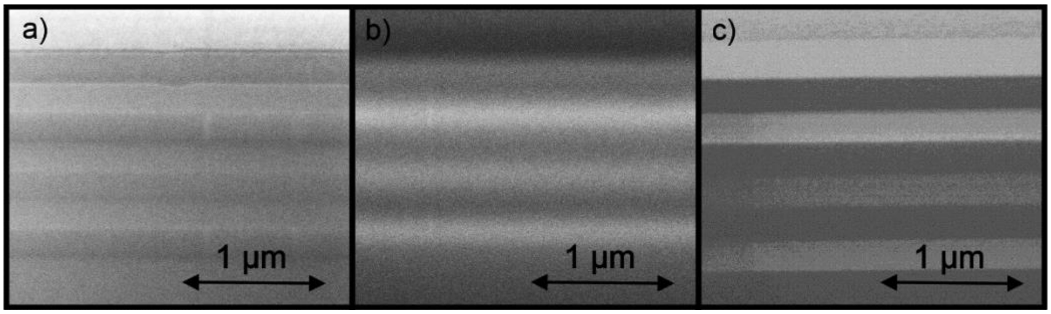

Figure 1: The images show cross sections of AlGaAs and GaAs semiconductor layers. The electron image (Fig. 1 a)) and the Ga ion image (Fig. 1 b)) have a much lower material contrast between the GaAs and AlGaAs layers compared to the Cs ion image (Fig. 1 c)). Here, even the different material composition X of the brighter $Al_XGa_{1-X}As$ *layers can be seen.*

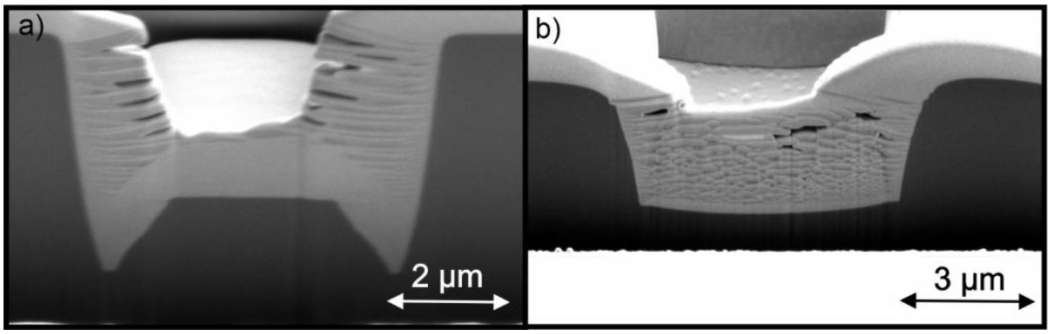

Figure 2: The electron images show the cross sections of rectangles milled with a Ga beam (Fig. 2 a)) and a Cs beam (Fig. 2 b)) into silicon (dark). The holes are filled with a platinum layer (bright). The bottom of the rectangle milled with Cs is much flatter and there are no "trenches" at the sides.

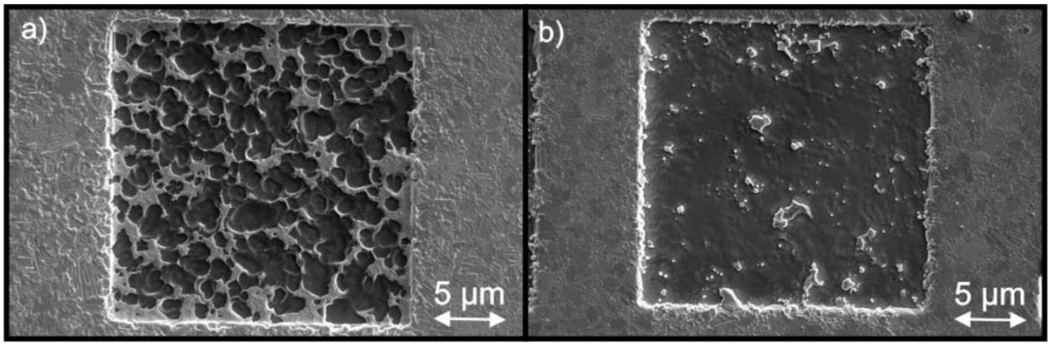

Figure 3: Electron images of a silver layer milled with a) Ga and b) Cs ions. Because of the polycrystalline structure the Ag layer normally has a very inhomogeneous sputter yield. Milled with the Ga beam silver is still present in the milled rectangle while the Ga ions are already milled deeply into the subjacent Si substrate. Milled with the Cs beam almost all silver is removed while the substrate is untouched.